Renewable and Sustainable Energy Reviews 30 (2014) 715–723

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Transition and transformation: A bibliometric analysis of two scientific networks researching socio-technical change

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ARTICLE INFO

Article history:
Received 27 February 2013
Received in revised form
28 October 2013
Accepted 12 November 2013
Available online 1 December 2013

Keywords:
Transition
Transformation
Bibliometrics
Citations
Scientific network
Sustainability

ABSTRACT

Sustainability policy in the early 2000s is based on and therefore influenced by scientific literature on 'transition'. The importance of this link has inspired the authors to explore the structure of cooperating authors and citation networks in the field. In order to understand 'transition' literature, we compare it with an alternative term for change, 'transformation', which is also used in the context of socio-technical shifts towards sustainability. We expose the different structures of these fields with an overview of keywords, key references, key authors, and the coherence between references and authors.

By analysing co-author and citation networks, we find large differences in these groups of documents. The transition literature is characterised by a large network of directly and indirectly cooperating authors with clear clusters; transformation literature contains smaller author networks. Key transition authors are predominantly Dutch. They repeatedly write together and cite each other's work. The transition literature is tightly knit with high degrees of internal references and a clearly distinguishable core. Transformation literature has fewer connections between authors and articles. The connecting articles, each with many global citations, form its basis.

This analysis can be used as a step to continue the debate on the role of transition and transformation literature in sustainability and renewable energy policy. The transformation literature teaches us that older streams of thought are still relevant and may be used as 'glue' for linking change with respect to sustainable energy to wider developments. Rediscovering existing literature in new combinations may lead to promising new views on sustainable energy.

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1364-0321
http://dx.doi.org/10.1016/j.rser.2013.11.013

1. Introduction

In the light of dwindling energy resources and increased pollution due to a myriad of emissions, governments since "Limits to growth" [30] and the oil shocks in the 70s have been trying to work towards a more sustainable society. The envisioned changes are said to require a different way of thinking and a different structure for our society [40]. In the international arena agreements were made, e.g. for banning CFKs and curbing CO_2 emissions [59], which were translated into national, regional and local policies.

In the early 2000s the Dutch Ministry of Environmental Affairs introduced a new concept called 'transitions' in their environmental policies [31] that built on a range of academic concepts from technology history, systems and complexity science, and management [42,46]. It met fertile ground and 'transition thinking' became important in the Dutch sustainable energy debate. Interestingly, the former head of Shell Netherlands headed a 'Transition Platform': a broad coalition of actors working towards innovation in sustainable energy. Later, the Task Force Energy Transition was formed [57], which became a coordinating council for energy initiatives [20]. While academic thinking spawned political debate, the reverse was also true: the transition movement became a reality that required further description and elaboration. Academics that research sustainable energy use in the Netherlands cannot avoid the strong influence of transition thinking over the last decade. Also beyond the Dutch borders the concept has gained ground [4, p. 12].

Another term that is mentioned when discussing long-term societal change in sustainable energy use is *transformation* (see e.g. Jacobsson and Johnson [21], Negro et al. [34]). Geels and Schot [15], Geels and Kemp [14], Suarez and Oliva [56], for instance, label transformation as change due to pressures in the societal environment. Transformations are discussed at different levels of analysis (e.g. organisational, legal, cultural) and include sustainable energy use and renewables as application domains.

Because transformation is a near-synonym of transition that is also used in the context of sustainable energy we argue that a comparison of the literature that uses these terms may help to understand the basis upon which the different researchers build. Our proposed method goes beyond standard literature analysis [5]. By using modern information technology in combination with graph theory [37,55] – in particular co-author analysis [6,54] and citation analysis [10] – we perform a more quantitative analysis of the scientific fundaments upon which researchers build and the networks they form in doing so. We believe that a network analysis can contribute to existing, more qualitative, analyses, e.g. the review of sustainability transitions by Markard et al. [27].

This method allows for formulating the following questions:

- Who are the key authors in the transition and transformation literature? *Who should I definitively meet?*
- What are the key papers in the transition and transformation literature? *What should I definitively read?*
- What is the structure of the scientific network in the transition and transformation literature? *Who is connected to whom? What clusters of approaches and energy and sustainability topics can be found?*

We aim to give clues about the usefulness of transition and transformation literature for energy and sustainability scholars by sketching the bigger picture of research on socio-technical shifts. This sketch includes an overview of clusters of researchers, approaches and application domains. The scientific structures we identify, provide new insight into the breadth and depth of this body of knowledge.

In Section 2, we elaborate on the approach that we took to obtain the structure and characteristics of the literature on transition and transformation. The results are presented and analysed in Section 3. Afterwards we draw conclusions in Section 4.

2. Approach

Science is a complex adaptive system [51]: an uncontrolled, bottom-up knowledge creation process that is partially steered by peer review, science ethics, and funding criteria. One of the outcomes of this process is the collection of scientific papers that focuses on particular subjects. These papers are embedded in their field through citations [10]. Papers refer to other papers to provide an intellectual or methodological basis, to support or oppose the approach taken and to judge the findings of the research performed. The metaphorical 'shoulders of giants' (which as a graph could be depicted as a tree), are papers referring to each other forming a network of papers and citations.

This network, in which papers form nodes and citations are the links, is a resultant of networks of co-authoring scientists citing others. The networks of papers and scientists co-evolve under the influence of aforementioned peer pressure, rules of conduct, and funding schemes. Thus, good science is perpetuated and good scientists are credited. On the other hand, due to the immense volume of scientific literature some potentially important findings may be forgotten. Moreover, self-organisation could lead to self-preservation, in which non-optimal outcomes are sustained instead of falsified. By analysing the networks in science – by means of citations *and* co-authorships – one may better understand the cohesion, quality, level, and coverage of a specific part of the literature.

We have used a structured keyword-based search to gather papers, citations, and authors in the fields of 'transition' and 'transformation'. The approach is summarized as follows (for a detailed description for repetition and verification purposes, see the Appendix):

1. Collection of scientific sources based on key terms. This can be done with a range of on-line tools such as Scopus,[1] Web of Knowledge[2] and Google Scholar.[3] We performed our search using the following key terms with Scopus. Scopus purportedly has a more European focus, encompasses more modern sources, and also lists some conference proceedings. The keywords 'transition' and 'transformation' were not searched in solo, but accompanied with additional keywords to gain enough focus in the search. For transition, we used the keywords 'sociotechnical transition', 'socio-technical transition', 'societal transition', 'technological transition' and 'transition management'. For transformation we used the same accompanying terms. We have deliberately *not included* keywords directly related to energy and sustainability, in order to let the relevance of transition and transformation for energy and sustainability emerge from our analysis. This relevance is confirmed in the results section.
2. For all sources we extracted the authors, citations, and keywords. Unfortunately, in Scopus or Web of Knowledge only scientific articles can be extracted. Therefore, books as primary sources are not taken into account. References to books, however, are recorded.
3. We drew a network graph of (1) links between authors, based on co-authorships, and (2) the links between papers, based on citations and co-citations.

[1] http://www.scopus.com.
[2] http://apps.webofknowledge.com.
[3] http://scolar.google.com.

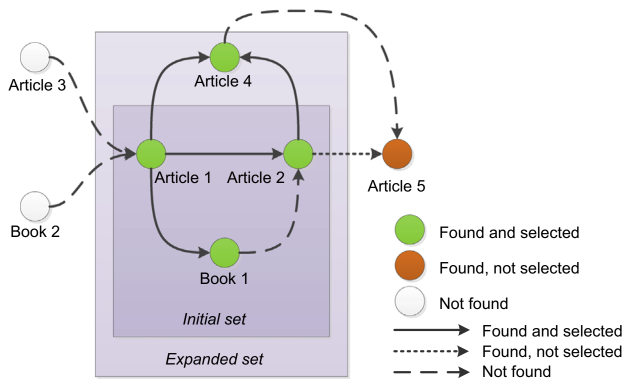


Fig. 1. This graph shows the method for our analysis: of all literature found by the keywords-based search (in the inner box), we collected the references and only selected those that are co-referenced by two or more of the articles we read. Article 4 is included in the analysis, whereas article 5 is not.

4. We compared the structure of the network graphs and identified key researchers and papers. In addition, we compared the result of the two searches (transition and transformation) and looked up the citations of the key papers in other fields.

We have indicated which sources are included and excluded in Fig. 1.

3. Results and analysis

3.1. Overview of the results

An overview of the results can be found in Table 1. The literature search resulted in ~400 documents for both the transition and transformation keywords. However, when the co-cited references were included[4] the transformation network increased to 518 documents, whereas the transition network increased to 922 documents. Thus, the network of scientific documents in the transition literature is larger than that of transformation.

The total number of citations within this group of co-cited references (the groups of 518 and 922 documents) is 648 and 2799. That means that within the set of papers found in our search – including the co-cited references – there are more links between the papers on transition than on transformation. Indeed, the number of citations found between the documents is more than 4 times larger for transition than for transformation. Per original document the number of citations found is 6.3 within the field of transition, with 1.6 for transformation. We can see that the papers on transition are strongly linked together. This is less the case for transformation. This suggests that the transition researchers form a more tight community.

We also counted the number of authors of the extended set and the links (i.e. co-authored papers) between those authors. We find more distinct authors in the transition literature in absolute terms (546 versus 325), but per document the ratios are similar. On average, documents on transition are written by 0.59 unique authors, while this average for transformation is 0.63.

Furthermore, the number of links between authors jointly writing a paper are not far apart. On average for transition author, there are 2.1 authors per paper, while for transformation the average is slightly lower (2.0). These numbers imply that there is not a large difference in the number of co-authors per paper, nor in the number of different authors in the field.

Table 1
Search statistics.

Search term	Documents in search	Expanded set	Total citations	Total authors	Co-authorships	HHI index
Transition	439	922	2799	546	596	0.0041
Transformation	396	518	648	325	333	0.0025

Table 2
Most frequently used keywords (excluding keywords containing transition or transformation).

Transition Keyword	*Count*	Transformation Keyword	*Count*
Sustainable development	23	Technology	6
Sustainability	18	Innovation	6
Innovation	16	Sustainable development	5
Governance	14	Social change	5
Change management	9	Technological change	4

We used the Herfindahl–Hirschman Index[5] to determine the concentration of authors in the field. Whereas both fields have a low concentration, the index for transition is considerably larger than the index for transformations.

Finally, the most frequently used keywords, listed in Table 2, show the strong focus on sustainability and innovation for both the literature on transition as well as transformation. The main difference is that the transition literature also focuses on management and governance and that transformation focuses on technology. The lower count for transformation implies a wider variety in keywords.

3.2. Co-author networks

A strong evidence for links between researchers is in joint publications [26]. When drawing networks based on authors as nodes and publications as links we found several separate author networks, both for transition and transformation. Table 3 provides an overview of the largest author networks in the transition and transformation literature. The networks not shown in this table only contain a few authors that have cooperated on one or two papers. We do not mention these, since they only portray the relations between the authors of those few papers.

In transition literature there is one huge author network containing 181 authors (see Fig. 2). Other authors are not connected to this network by co-authoring references. The smaller networks are one of 22 authors with Scholtz as key author (the one with most papers), and another of 18 authors with Folke and Carpenter as key authors.

For the transformation literature, the largest network is a lot smaller: 19 authors, led by Kemp (see Fig. 3). There is only one other relevant network that contains 14 authors, the one led by Billari.

The topology of the networks provides additional insight in the structure of the different research themes within the field. Such thematic clusters can be shown by grouping highly interconnected authors. The visualisation of such clusters can be achieved by

[4] The initial sets of papers from the search are expanded with the documents they cite, but only if these are cited by more than one paper. We label the total set of papers as the *expanded* set of documents.

[5] The HHI is normally used to calculate market concentration. It is found by $HHI=\sum_{i=1}^{n} M_i^2$, where n is the number of authors, M_i is the number of papers for author i, divided over the total number of papers. A higher HHI indicates a higher concentration.

Table 3
Author networks with 10 or more authors. The listed key authors are the most central in the network.

Size	Key authors
Transition	
181	Van den Bergh, Geels, Hekkert, Jacobsson, Kemp, Loorbach, Rotmans, Smith, Vergragt, Voß
22	Scholtz
18	Carpenter, Folke
Transformation	
19	Kemp, Schot, Truffer
14	Bahler, Beets, Billari, Desequelles, Fokkema, Solaz, Speder, Vikat

using a network visualisation tool with an appropriate network layout algorithm.[6]

Looking at the largest networks in more detail, we find nine separate clusters of transition authors outside the center. We define the center as the cluster surrounding Rotmans, Kemp, and Geels. An overview of these clusters can be found in Table 4. In Fig. 2, the colours indicate those clusters. What can be observed from this analysis, is that authors cluster based on their approaches in combination with their application domains. While the approaches vary (from management approaches to modelling), the strong link between the transition literature and renewable energy and sustainability is in their applications. For most clusters, relevant energy and sustainability applications can be identified. These are highlighted in the third column, with for example the diffusion of renewable energy technologies and sustainability policies.

Such clustering is also possible with the transformation literature, but the literature consists of many smaller, unconnected sets of authors.[7] Some of the topics of these smaller sets relate to e.g. the change from a Eastern European guided economy to a market economy, the shift from an industrial towards an information society, and fertility and demographics (the latter is the Billari cluster, mentioned in Table 3). The largest set of 19 connected authors is shown in Fig. 3. In this set of 19, four clusters can be distinguished, of which core topics are shown in Table 5 (and represented as different colours in Fig. 3). Also for transformation, we identified relevant energy and sustainability applications. Interestingly, all authors of this set also occur in the transition author network.

3.3. Core transition and transformation references

An overview of the most cited documents (in the expanded set) are listed in Table 6. One of the striking differences between the two sets is that the number of citations within our set – the in-degree – is far higher for transition. The average for the top documents on transition is 37; for transformation this is eight times lower, 4.5. In great contrast, the number of citations as listed by Google Scholar is more than four times higher for transformation: the average for the top on transitions is 1409, whereas for transformation this is 5506. Even if you argue that the average is not a good indicator, 'key papers' with very high citations are also more prominent in the transformation literature. There is one reference for transition and no less than nine references for transformation that have a very high number of citations (i.e. 1k–23k). Apparently the core documents part of and underlying the transformation literature contains a significant number of references that are important in a broader scientific sense. It must be noted that the transformation literature cases itself on older references (thus increasing the chance of amassing citations). The average age of the sets lies far apart: the top transition references stem from 2002 on average, compared to 1982 for transformation.

The multiple occurrence of authors in the top is higher for transition (10 authors) than for transformation (6 authors). For transition, the top list (ordered by occurrence): Geels (6), Kemp (5), Rotmans (4), Schot (3), van Asselt (2), Berkhout (2), Hoogma (2), Loorbach (2), Smith (2), and Stirling (2). For transformation, the duplicate authors in the top list is shorter: Kemp (4), Hoogma (2), Nee (2), Nelson (2), Schot (2), and Winter (2).

The fact that more others occur multiple times in transition cannot be explained by the lower amount of authors in the transition literature: the total number of different authors is not far apart. There seems to be a tendency of the top authors on transition to write together.

In addition, the origin of the authors occurring multiple times, is noteworthy: except for Smith and Stirling, all of the transition authors are Dutch. On transformation, only three of the duplicates are Dutch (and they also appeared in the top on transitions).

Looking at the mode of publication, Research Policy is the most important journal for both fields. The publication of books, however, is also very common, particularly for transformation. There are surprising documents in the top references regarding transition. First, there is the inaugural lecture of Rotmans. Second, it is surprising that a letter to the editor by Shove and Walker [49] in this journal is in the top list on transition. This letter to the editor is titled *CAUTION! Transitions ahead: Politics, practice, and sustainable transition management* and criticizes the transition management literature. There has been a response by Rotmans and Kemp [45] titled *Detour ahead: A response to Shove and Walker about the perilous road of transition management*. And, in response, an article by Shove and Walker [50], titled *Transition Management and the politics of shape shifting*. However, both responses are not in the top list.

3.4. Citation networks

Finally, one can look at the depiction of the full network of *documents*, linked by citations. For transition this leads to Fig. 4. The nodes (documents) with the highest in-degree are the ones that are cited most. We consider these key references and in the graph they are given a larger size. The result is a tightly knit graph, indicating a large number of cross-references between authors, which is what we expected after our analysis of author networks. What we further notice is that all top articles – the largest nodes – are in the center, suggesting that they belong together in the sense that they are cited together in other publications.

When we compare this graph to the transformation-related search, Fig. 5 emerges. Although the initial number of documents is roughly the same (~400), the resulting graph looks decidedly different. The graph is split up in several different sub-clusters that correspond to different groups of researchers interested in societal transformation. The analysis of author networks showed that the transformation authors are not part of the same network. This citation analysis demonstrates that although authors do not write together, they are aware of each others' work. Thus they can still be considered a somewhat coherent field.

4. Conclusion

In order to understand the literature on energy and sustainability – particularly related to *change* – we have explored the

[6] The graphs shown in this paper are produced using Gephi with Force Atlas and Yifan Hu layouts. The coloured clusters have been identified using Gephi's Modularity function.

[7] The fact that authors are unconnected does not mean that they do not use the same literature. This explains the large network of linked documents in Fig. 5.

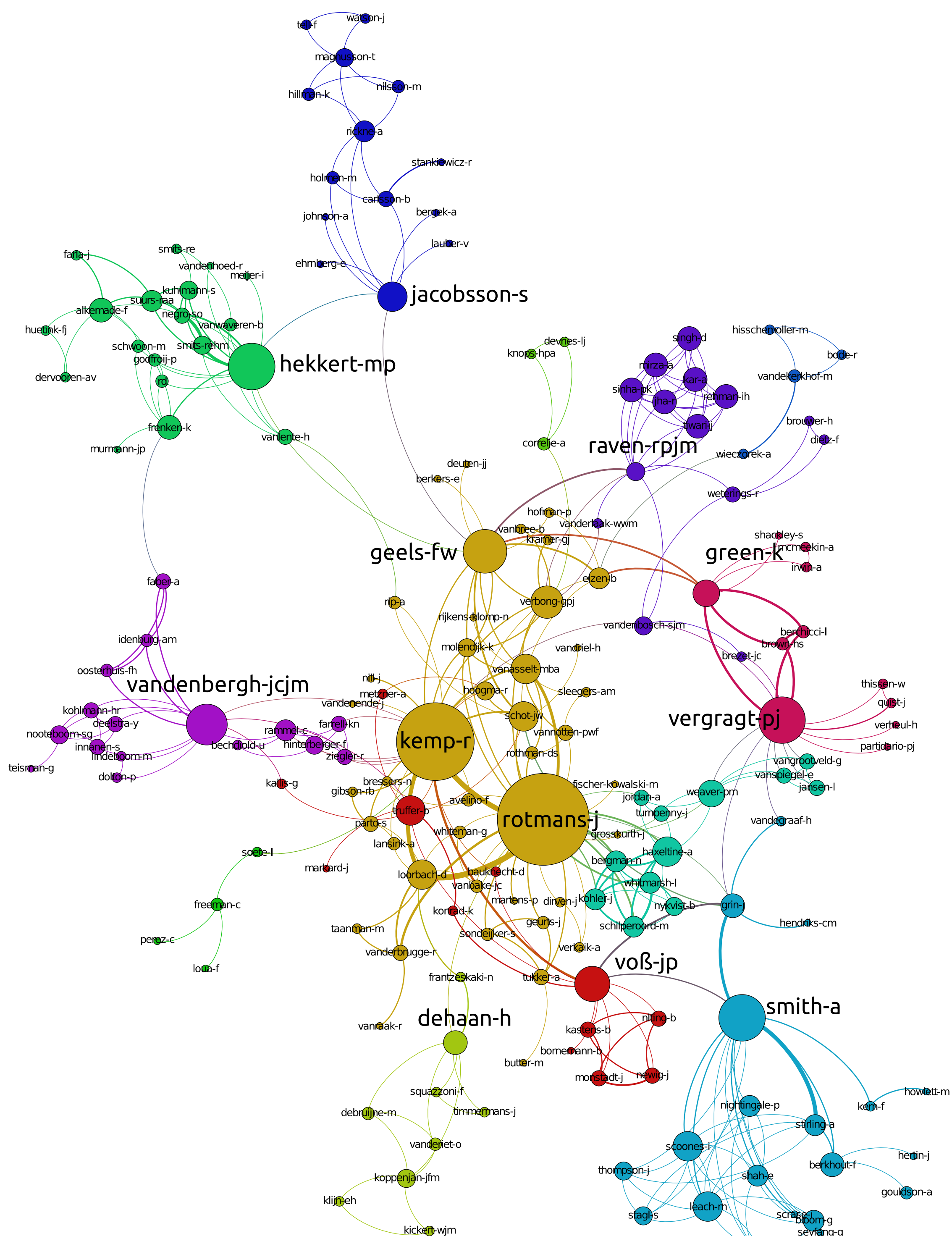


Fig. 2. Main network of 181 transition authors. The nodes represent authors. The size of the node represents the number of papers written. The width of the edges indicates the number of co-authored publications between two authors. The colour of the nodes represent different clusters of authors. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

intellectual core of transition and transformation literature. By comparing the structures of the literature, we have made an overview of the key papers that researchers in these fields should certainly read, we found clues as to the coherence of the fields, and identified opportunities for future developments.

Relevance to energy and sustainability: Although the terms transition and transformation are used for processes of change in many contexts (e.g. from chemistry to geopolitics) we have made the sets of documents comparable by focussing on change processes related to socio-technical systems. We would like to emphasise that *sustainability* and *energy* were not selection criteria; the extent to which there is a focus on sustainability and energy is an emergent finding of this analysis. This focus is confirmed by the fact that sustainability appears in the top five keywords for both terms (see Table 2). The analysis of the author clusters (Tables 4 and 5) confirms that energy and sustainability

are key application domains, e.g. energy and sustainability policy and particular energy technologies.

The majority of the *transition* literature is linked to sustainability as a normative goal and energy emerged as the dominant topic. The analysis underpins that the notion of *transition* is strongly linked to the Dutch sustainable policy context (as illustrated by the key articles and authors). In *transformation* literature, energy and sustainability are often placed within a larger change process, such as economic development, demographics, or the change from a communist to a capitalist society. Also, there seem to be fewer normative, prescriptive approaches and more inquisitive, historical practices.

Identifying key authors and key literature: The approach we have described here is a valuable help in identifying key authors and literature in the fields of sustainability and energy. Table 3 provides us with the summary of the key authors and Table 6 displays the top documents within these fields. For researchers new to the field, these provide a guideline to the heart of the discussion. For already active researchers, it shows whom to contact or to seek collaboration with. For both transition and tranformation, the key publications are concentrated in “Research Policy”.

Structure of the scientific network: We also find interesting characteristics as to the nature of the scientific networks. Figs. 4 and 5 provide some clues. Together with the information from Tables 3 and 6, we conclude that the transition network is closer knit, uses more co-authorship, and refers more to the same key references. In contrast, the transformation network covers a wider range of topics and thus one dominant core cannot be

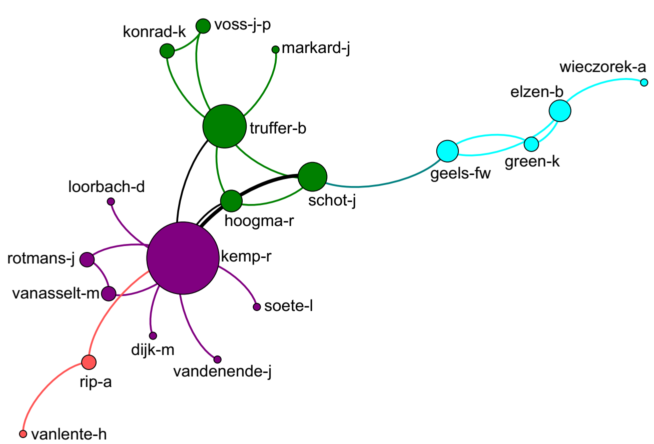


Fig. 3. Main network of 19 transformation authors (who to a large extent coincide with transition authors). The nodes represent authors. The size represents the number of papers written. The width of the edges indicates the number of co-authored publications between two authors. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

Table 5
Clusters in the main transformation author network represented in Fig. 3.

Core author	Core approaches – application domains
Kemp	Strategic niche management – environmental policy
Truffer	Innovation processes in large technical systems – sustainable transport and utilities
Geels	System innovation – sustainability
Rip	Technology-society interface

Table 6
Documents with most citations within this research's set of publications (*a*). Also Google Scholar citations are listed (*b*). Documents that explicitly focus on sustainability and energy are denoted by (⋄).

Document	Source	Citations	
Transition		*a*	*b*
Rotmans et al. [46] ⋄	Foresight	75	512
Geels [11]	Research Policy	68	675
Rip and Kemp [42] ⋄	In Rayner and Malone [41]	53	664
Smith et al. [52] ⋄	Research Policy	50	352
Kemp et al. [23] ⋄	Techn. An. & Strat. Man.	48	678
Geels and Schot [15]	Research Policy	42	365
Elzen et al. [8] ⋄	Book	40	225
Loorbach [24] ⋄	Book	38	225
Geels [13] ⋄	Book	30	307
Nelson and Winter [36]	Book	27	19,735
Berkhout et al. [2] ⋄	In Elzen et al. [8]	26	225
Rotmans et al. [47] ⋄	Report by MERIT	24	7
Geels [12]	Research Policy	24	0
Hoogma et al. [18] ⋄	Book	24	23
Rotmans [44] ⋄	Inaugural Lecture	22	8
Shove and Walker [49] ⋄	Environment and Planning A	22	130
Loorbach and Rotmans [25] ⋄	In Olsthoorn [38]	20	117
Transformation		*a*	*b*
UNDP [58]	Human Development Report	7	295
Rip and Kemp [42] ⋄	In Rayner and Malone [41]	7	664
Geels [11]	Research Policy	5	675
Kemp et al. [23] ⋄	Techn. An. & Strat. Man.	5	678
Smith et al. [52] ⋄	Research Policy	5	352
Nelson and Winter [35]	Research Policy	5	1769
Appadurai [1]	Book	4	10,923
Dosi [7]	Research Policy	4	4646
Freire [9]	Book	4	599
Granovetter [17]	American Journal of Sociology	4	17,713
Hoogma et al. [18] ⋄	Book	4	23
Hughes [19]	In Bijker et al. [3]	4	1339
Kemp and Loorbach [22] ⋄	In Voß et al. [61]	4	89
Marx [28]	Book	4	19,852
Nee [32]	American Sociological Review	4	788
Nee [33]	Admin. Science Quarterly	4	692
Polanyi [39]	Book	4	12,353
Rona-Tas [43]	American Journal of Sociology	4	400
Schultz [48] ⋄	Book	4	43
Nelson and Winter [36]	Book	4	19,735
Giddens [16]	Book	4	22,296

Table 4
Clusters in the main transition author network represented in Fig. 2.

Location	Link to center	Core approaches – application domains
Center	Rotmans, Kemp, and Geels	Transition management, transformation, socio-technical change – sustainable development
Upper-left	Hekkert – Geels	Functions of innovation systems – sustainable technology development
Upper-mid	Jacobbson – Geels	Diffusion of renewable energy technologies
Upper-right	Raven – Geels	Strategic niche management – sustainable mobility, biogas, hydrogen
Mid-left	Van den Bergh – Kemp	Evolutionary and environmental economics – renewable energy sources
Mid-far-right	Vergragt and Green – Geels	Social innovation and participation – hydrogen fuel cells
Mid-right	Haxeltine – Rotmans	Modelling – sustainable mobility
Lower-left	De Haan – Rotmans	Computational and mathematical models
Lower-mid	Voß – Kemp	Reflexive governance – sustainability foresight in utility sectors
Lower-right	Smith and Grin – *via Voß*	Learning, governance, regimes – environmental policy

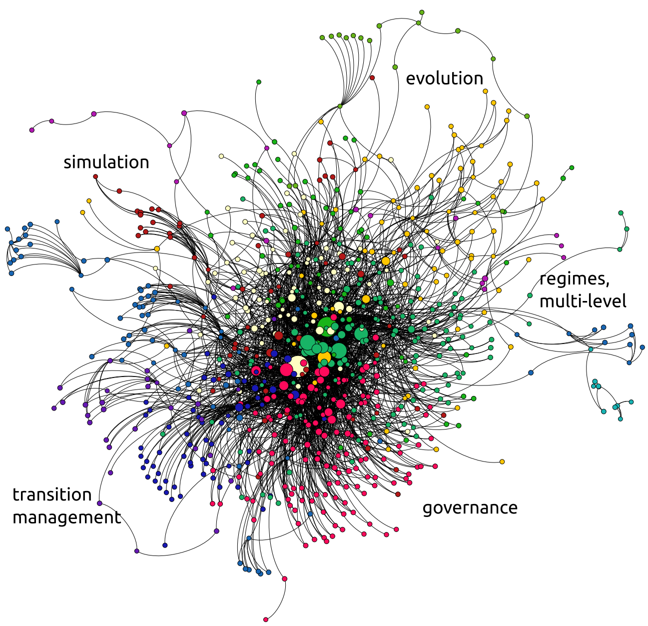


Fig. 4. The 'transition' citation network with a rough indication of central topics (in colour). Large nodes are cited more frequently. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

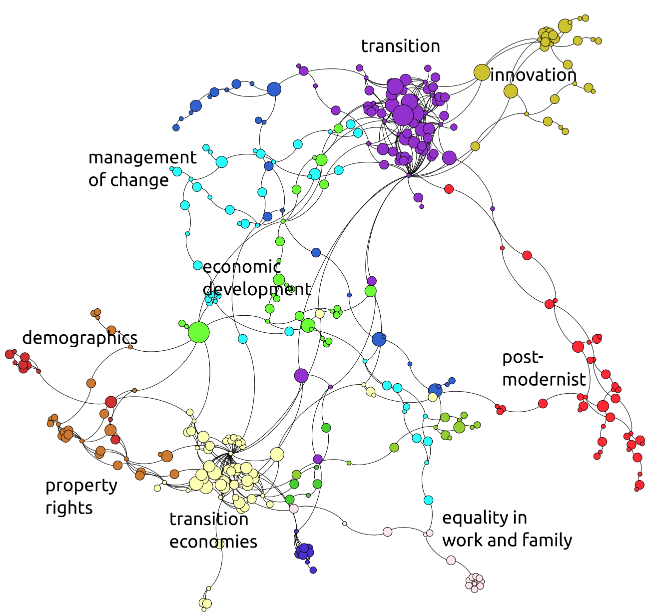


Fig. 5. The 'transformation' citation network with a rough indication of central topics (in colour). Large nodes are cited more frequently. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

identified. By using network analysis, however, we showed that the wide range of topics is indeed related: the key references on transformation form the links between the topics. One could say that the basis for transformation research is broader. As a consequence, the fact that individual authors do not form large networks on the topic of transformation does not imply that they are unrelated.

One could see transition as a more coherent field, which is substantiated by the fact that many of the authors are members of the Sustainability Transition Research Network (STRN). To our knowledge, such a network does not exist for transformation research (although more specific networks exist, e.g. the Geographies of Finance and Post-socialist Transformations Research Network).

We believe that the scope of the transition field (although still large) is smaller than that of transformation, which also leads to more coherence. This, however, also has a negative side: there is a risk of limited learning through in-crowd behaviour and groupthink [53]. Repeatedly writing together (co-authorship) and citing each other's work (cross-referencing) could be an indicator of myopia to larger (scientific) developments. The difference between the in-field citations and global citations (columns *a* and *b* in Table 3) suggests that this might be the case. Researchers should be aware of this danger.

The references in Table 3 also suggest that the key transformation literature is older. This suggests that transformation literature is less connected to recent developments and partially explains the large number of global citations (column *b*). These citations suggest that the key documents on transformation still contribute to furthering our knowledge on sustainability and energy.

The societal contribution is hardly captured by counting citations. For transition, the societal contribution appears to be an important goal of the researchers (which is shown in the Dutch policy context). Transformation takes a more descriptive stance; this does not necessarily imply less impact. More research into societal pay-back would enlighten this debate, but conclusive evidence may only be available in several decades' time.

Relevant streams of theory and ideas: The use of the author and reference maps allows for the visual identification of clusters. In transition, these clusters largely overlap, although there are differences between the more analytical clusters (e.g. evolutionary and multi-level analysis) and the more design-focused (e.g. transition management and governance). In transformation, there are also transition and innovation clusters – this shows the overlap between both terms – but these clusters lie at a further distance from others, such as demographics and economic development. The clusters relate to large, macro-level changes in societies.

In this paper, a clustering algorithm identified the clusters of authors and documents. However, we named them based on common terms in the titles of the documents. A next step in this research would be key term extraction and corpus analysis (the co-occurrence of words in a set of texts [60, cf.]). We believe that Figs. 4 and 5 already show some clearly identifiable streams.

Outlook: We emphasise that bibliometrics is only one of the necessary approaches to understand strengths and weaknesses of the literature. This analysis should be enriched by systematic in-depth exploration. McCain [29] suggests calling in help for validating the findings of bibliometric research. With this analysis we open up the discussion on new directions for the literature on energy and sustainability.

The tools demonstrated in this paper structure thinking about research fields. For those visually inclined the fancy figures already provide cognitive 'hooks' to help to see the coherence between documents and authors: like a street map that helps to understand a city and identify main buildings, thoroughfares, and neighbourhoods (or ghetto's). The transformation literature teaches us that older streams of thought are still relevant and may be used as 'glue' for linking change with respect to sustainable energy to wider developments. Rediscovering existing literature in new combinations may lead to promising new views on sustainable energy.

Further bibliometric analysis could lie in the co-citation analysis identifying which documents or authors are always mentioned together. This would indicate either interesting scientific disputes or be an additional indicator for *schools of thought*. Also, with the help of corpus analysis the coherence between specific key terms can be further investigated. A methodological advancement would

be the dynamic representation of the growth and decline (!) of literature. One can imagine that certain key references are very popular but then, like fashions, fade away to become hip again after two decades. This way, the transition and transformation of scientific fields can be better understood, and with it the influence they have on sustainable energy policy.

Acknowledgements

This work was supported by the Next Generation Infrastructures Foundation,[8] by the Energy Delta Gas Research program, project A1 – Understanding gas sector intra-market and inter-market interactions,[9] and by the Knowledge for Climate program, project INCAH – Infrastructure Climate Adaptation in Hotspots.[10]

Appendix A. Detailed steps for the literature network analysis

For researchers interested in repeating this analysis, we describe the steps in detail below. A number of linux-based scripts and the results are available online.[11]

A.1. Search in Scopus[12]

- Use the document search to query for a number of search terms in titles, abstracts and keywords, where the search terms are separated by AND.
- Select all documents found and use the export function. Select the complete format and export to a csv file.
- Combine the resulting csv files (if multiple queries were used).
- Use the scripts to reformat the resulting csv file to generate both a file with all citation combinations and a file with all author combinations.
  - *generateDocumentEdgeList.sh* – Run this script to generate an edge list for each citation that can be extracted from the Scopus file. The list will be saved to disk.
  - *generateAuthorEdgeList.sh* – The script to generate the edge list for co-authors.
  - *generateKeywordOverview.sh* – The script to generate an overview of keywords used.

A.2. Harmonise the result in Google Refine[13]

- Both lists need to be improved because the same author, documents and keywords have different identifiers (for example 'Nelson, R.' and 'Nelson, R.R.').
- Use the Cluster and edit function to find similar values and determine which should be duplicates. There are various clustering algorithms implemented. Also use this function to combine various editions of the same publication into one document identifier.
- Change everything to lower case. Remove malformatted references.
- Use the Facet by Blank function to deselect empty cells.
- Export the result as a tab-separated file.

[8] http://www.nextgenerationinfrastructures.eu
[9] http://www.edgar-program.com
[10] http://knowledgeforclimate.climateresearchnetherlands.nl
[11] https://svn.eeni.tbm.tudelft.nl/LiteratureAnalysis/TransitionAndTransformation
[12] http://www.scopus.com
[13] http://code.google.com/p/google-refine/

A.3. Visualise and explore literature network with Gephi[14]

- The harmonised lists are imported in Gephi to study the network.
- Check by hand for duplicate nodes and use the Merge nodes function. Remove erroneous nodes (such as commas only, or 'from china').
- Use the data explorer function to calculate general statistics of the networks and get an overview of the mostly cited papers.
- Format the colour of the nodes based on the cluster (as found by the modularity statistic). Format the size of the nodes to reflect the number of times the document has been cited within the network of documents. For the authors network, use the author name as labels.
- Use Yuh Han and Force Atlas 2 algorithms to reposition the nodes in the graph. Select as filter the Giant Component to remove all unconnected groups of nodes.
- Export the graphs as a PDF file.

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